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(54) Title: SELF-CORRELATION DETECTION AND IN-BAND AND OUT-OF-BAND SIGNAL DETECTION FOR AUTOMATIC GAIN CALIBRATION SYSTEMS

(57) Abstract: An embodiment of the present invention provides an automatic gain control system for a wireless receiver that quickly differentiates desired in-band signals from high power out-of-band signals that overlap into the target band. The system measures power before and after passing a received signal through a pair of finite impulse response filters that largely restrict the signal's power to that which is in-band. By comparing the in-band energy of the received signal after filtering to the total signal energy prior to filtering, it is possible to determine whether a new in-band signal has arrived. The presence of this new in-band signal is then verified by a multi-threshold comparison of the normalized self-correlation to verify the presence of a new, desired in-band signal.

SELF-CORRELATION DETECTION AND IN-BAND AND
OUT-OF-BAND SIGNAL DETECTION FOR
AUTOMATIC GAIN CALIBRATION SYSTEMS

BACKGROUND OF THE INVENTION

5   Field of the Invention

The present invention is directed to communication systems. More particularly, the invention is directed to receivers in wireless communication systems. Even more particularly, the present invention is directed to automatic gain control systems for such wireless communication system receivers.

10   Background of the Related Art

The use of receivers in wireless systems such as radio and cellular communication systems is well-known in the art. FIG. 1 shows a typical superheterodyne receiver design 10. Here, a radio frequency (RF) signal is received on antenna 15 and provided to RF amplifier 20. The RF signal is amplified by the RF amplifier 20 and in mixer 25 mixed with a signal from a local oscillator 30. This

15   produces an intermediate frequency (IF) signal that is amplified in an IF amplifier 35 and filtered in a bandpass filter 40. The filtered IF signal is again amplified by an IF amplifier 45 and mixed in a product detector 50 with a signal from a beat frequency oscillator 55. The result is a signal that is amplified by a baseband amplifier 60 and digitized for further processing by an analog-to-digital (A/D) converter 65.

In such receivers, less amplifier gain is needed for strong signals, and it is important that a very

20   strong signal not be amplified to the point that when amplified it distorts received information signals, overloads system components and possibly damages the components. For this reason, receivers typically have some sort of automatic gain control (AGC) system which controls one or more of the system amplifiers 20, 35, 45 and 60 to maintain the amplified signals within certain ranges (this control may be, e.g., through a bias applied to the amplifiers). In FIG. 1, the AGC unit 70 receives an IF input output by

25   the IF amplifier 45 and uses it to generate bias signals controlling the RF amplifier 20 and the IF amplifiers 35 and 45.

SUMMARY OF THE INVENTION

An embodiment of the present invention provides an automatic gain control system for a wireless receiver that quickly differentiates desired in-band signals from high power out-of-band signals that

30   overlap into the target band. The system measures power before and after passing a received signal through a number of filters that largely restrict the signal's power to that which is in-band. By comparing the in-band energy of the received signal after filtering to the total signal energy prior to filtering, it is possible to determine whether a new in-band signal has arrived. The presence of this new in-band signal is then verified by a multi-threshold comparison of the normalized self-correlation to verify the presence

35   of a new, desired in-band signal.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of an embodiment of the present invention are better understood by reading the following detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings, in which:

5   FIGURE 1 shows the structure of a communications receiver according to the prior art;

FIGURE 2 shows the structure of a communications receiver according to an embodiment of the present invention;

FIGURE 3 shows the structure of an automatic gain control mechanism in the embodiment of FIG. 2;

10   FIGURES 4 and 5 show desired characteristics of a gain-controlled signal;

FIGURE 6 shows characteristics of A/D converter saturation in the embodiment; and

FIGURES 7A, 7B, 8A and 8B show characteristics of in-band and out-of-band signals.

DETAILED DESCRIPTION OF
PRESENTLY PREFERRED EXEMPLARY EMBODIMENTS

15   The basic structure of a receiver of an embodiment of the present invention is shown in FIG. 2. Here, a wideband antenna 115 receives a radio frequency (RF) RF signal and provides it to an RF amplifier 120, and a particular channel or signal within the band is preferably selected by varying the local oscillators 130 and 180. In the embodiment, the RF signal preferably conforms to the IEEE 802.11a standard, has a frequency in the 5 GHz band and is quadrature modulated to carry 6 to 54 Mbps. In this

20   embodiment, the signal can carry up to 54 Mbits of data and lies within one of twelve 20 MHz wide slots, eight within a 5.15 - 5.35 GHz band and four within a 5.75 - 5.85 GHz band. The signal in this embodiment is a coded orthogonal frequency division multiplexed (OFDM) signal using 52 subcarriers spaced 312.5 kHz apart. It is understood, however, that while the following detailed description of the present invention is made in the context of an IEEE 802.11a system, that the inventions described herein

25   have application to many different types of communication systems, and are not limited to systems operating within the IEEE 802.11a standard. For example, as described hereinafter the present invention described operating upon the short and long training symbols in an IEEE 802.11a system, but it is noted that the teachings related thereto can be generalized to any training sequence made up of one or more sinusoids. Thus, for example, power measurements can be made based upon half of a period of a slowest

30   frequency sinusoid that exists within a training symbol containing a plurality of sinusoids, with each of the plurality of sinusoids having a frequency that is an integer multiple of the slowest frequency sinusoid. In 802.11a system this translates to half of a short training symbol sequence.

The amplified RF signal is mixed with a signal from a local RF oscillator 130 supplied to an RF mixer 125 to generate an intermediate frequency (IF) signal that is fed to an IF amplifier 135. Preferably,

35   the sum of the frequencies of the local RF oscillator 130 and local IF oscillator 180 are in the range 5.15 - 5.35 and 5.75 - 5.85 GHz, with the ratio of the RF oscillator frequency to the IF oscillator frequency being 4:1. In the embodiment, the local oscillators 130 and 180 are preferably in a floating IF arrangement in

which they both are variable, rather than a fixed IF arrangement where, e.g., only the RF local oscillator 130 is variable.

The amplified IF signals are supplied to an in-phase mixer 175-IP and a quadrature mixer 175-Q, respectively. One of the in-phase mixer 175-IP and the quadrature mixer 175-Q is directly driven by a

5   local IF oscillator 180, and the other of the in-phase mixer 175-IP and the quadrature mixer 175-Q is driven by the local IF oscillator signal after it is phase-shifted by 90° in a phase shifter 185. In this way, in-phase (IP) and quadrature (Q) components of the received RF signal are obtained at the outputs of the in-phase mixer 175-IP and quadrature mixer 175-Q, respectively.

The mixed IF signals pass through low-pass filters 140-IP and 140-Q to select the desired channel

10   and remove spectrally distant components not of interest, and are amplified by two series of baseband amplifiers 145-IP and 145-Q. Though two baseband amplifiers are shown in each branch, a different number of amplifiers may be used. Almost any desired baseband gain step arrangement may be developed using baseband amplifiers having appropriately selected programmable gains in a particular order.

15   Preferably, the low-pass filters 140-IP and 140-Q are two-pole elliptical filters having a 3 dB corner at 28 MHz. Moving from the analog to digital domain, the baseband amplifier outputs are fed to A/D converters 190-IP and 190-Q which digitize the in-phase and quadrature component signals, preferably with a frequency of 80 MHz, to a resolution of nine bits, and an input dynamic range of –500 mV to 500 mV.

20   Preferably, the A/D converters are pipeline A/D converters; however, the invention is not so limited. For example, sigma-delta or other converters may be used in their place.

An analog channel filter and/or anti-aliasing filter may advantageously be placed before the A/D converters 190-IP and 190-Q. In the preferred embodiment, the combination of the analog filters perform adjacent blocker rejection of 4 dB and an alternate blocker rejection of 20 dB. With a worst case of an

25   adjacent blocker 16 dB larger and an alternate blocker 32 dB larger, a received blocker at the A/D converter input can be 12 dB higher than the in-band signal. As is known in the art, an adjacent blocker is an interference signal adjacent to or overlapping the frequency band of interest, while an alternate blocker is an interference signal farther away from the frequency band of interest.

The digitized I/Q component signals are provided to an automatic gain control (AGC) unit 170

30   whose operation with respect to the present invention will be described in greater detail below. The AGC 170 analyzes the I/Q component signals as described in greater detail below and generates gain control signals based thereon. These gain control signals are provided to the amplifiers 120, 135, 145-IP and 145-Q as shown by the dotted line in FIG. 2.

More specifically, as shown in FIG. 3 the digitized IF signals from the A/D converters 190-IP and

35   190-Q are passed through leaky bucket filters 245-IP and 245-Q and finite impulse response (FIR) filters 205-IP, 210-IP and 205-Q, 210-Q. The first FIRs 205-IP and 205-Q are decimation filters that eliminate every other sample from their respective streams to reduce the data sampling rate from 80 MHz to 40 MHz for a normal 8.5 MHz single-sided bandwidth packet. The second FIRs 210-IP and 205-Q are

standard low-pass filters which remove any residual adjacent or aliased blockers before sending the data to the self-correlator 225 and a power detector 220. Two power measurements are taken within the AGC 170 — one from the output of the second FIR filter 210 by the power detector 220, and another from the output of A/D converters 190-IP and 190-Q by another power detector 215. These measurements are provided to AGC control logic 230 as will be described in greater detail below.

Although this embodiment uses digital FIRs, other types of filters, including analog filters, may be used in their place. If the system is not oversampled, the filters are preferably analog.

AGC control logic 230 receives the power measurements from power detectors 215 and 220 and uses them to control a gain control generator 235 to output analog gain control signals for each of the RF amplifier 120, the IF amplifier 135, and individual ones of the baseband amplifiers 145-IP and 145-Q. In the embodiment, the AGC control logic 230 provides a control word, ten bits in length in the preferred embodiment, to the gain control generator 235, and the gain control generator 235 generates appropriate control signals for the amplifiers. These gain control signals are fed back to the RF amplifier 120, the IF amplifier 135 and the baseband amplifiers 145-IP and 145-Q to control the gain of each as described above.

The embodiment uses an application-specific integrated circuit to implement the AGC control logic 230; however, an appropriately programmed processor, either embedded or discrete, or other appropriate device, may be used as well.

It should be noted that although FIG. 3 shows various components within the AGC 170 to be separate from one another, it is possible that two or more units may be integrated into one. For example, the AGC control logic 230 is shown separately from the FIRs 205, 210, power detectors 215, 220 and self-correlation unit 225; however, several of these may be combined into a single processor appropriately programmed to perform these functions. Further, a programmed processor need not be used and one or more of these components can be implemented in dedicated hardware.

The AGC 170 may control a DC offset control unit 240 to provide analog offset control signals to one or more of the baseband amplifiers 145-IP and 145-Q. DC offset control is done to ensure that the analog signals provided to the amplifiers and A/D converters 190-IP and 190-Q are properly centered and quantized.

AGC Operation

In the embodiment, the control logic 230 first checks to see if the signal is sufficiently saturating either of the A/D converters 190-IP and 190-Q. If so, a quick drop gain control procedure is executed; if not, a base gain control procedure, also described below, is executed.

Next, the AGC base gain control logic 230 determines whether the received signal is within a preferred range as described below. If so, no gain control is needed; otherwise, a gain control procedure described in greater detail below is executed.

Then, the AGC system 170 attempts to identify an in-band signal using strong signal and weak signal detection techniques, as described in greater detail below. If a signal is found, the detection process is complete; if not, the detection process is repeated on the next portion of the signal. Weak signal detection and strong signal detection are independent and complementary features. As described further

5   herein, for strong signal detection, it is determined that a signal may exist by the arrival of a stronger signal necessitating a drop in receive gain, whereas for weak signal detection, it is determined that a signal may exist due to a sudden increase in measured in-band power at least proportional to the increase in total power at the ACC (while not requiring a gain change), followed shortly by a self-correlation exceeding thresholds. It is noted that it is preferable to disable weak signal detection, typically for a few

10   microseconds, if a gain change is made, since self-correlation will not be valid until the entire viewing window for self-correlation is filled with post-gain-change values. Thus, weak-signal detection is used for arriving signals not large enough relative to blockers or noise to cause gain changes, and strong signal detection for larger arriving signals. And for strong signal detection, that a new signal has arrived is determined based upon whether a coarse gain drop or quickdrop gain results, as described below.

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AGC Base Gain Control For a Coarse Gain Change

In operation, the AGC 170 must adjust receiver gains so that the received signal can properly be quantized by the A/D converter 190. If this signal is too big at the A/D converter input, the signal will be distorted by saturation. If the signal is too small at the A/D converter input, the quantization noise of the

20   A/D converter 190 will render the received signal-to-noise (S/N) ratio too low for correct detection. For ·this purpose, the AGC control logic 230 digitally controls the analog variable gain stages mentioned above using the gain control unit 235. Preferably, the embodiment's gain control has a dynamic range of 93 dB – 51 dB in the combined RF and IF stages 120 and 135 and 42 dB in the baseband stage 145.

The power detector 215 estimates the total digitized power at the A/D converters 190-IP and 190-

25 · Q by summing a window of instantaneous power calculations for half of a preamble short symbol window in an 802.11a signal (400 ns) for a total of 16 samples. For example, consider a signal coming out of a nine-bit A/D converter 190 with a range of [-256, 255], and measurement of power for this signal over a 16-bit sample window in half a preamble short symbol window. To do this, the AGC control logic 230 calculates the instantaneous power adcpwr1 on the A/D converter output stream *adcoutput* as

30   $$adcpwr1 = \sum_{k=0}^{15} (real(adcoutput[k]))^2 + (imag(adcoutput[k]))^2 \qquad (1)$$

This power measurement is then put into a log table, where its maximum value is zero. Thus, for a fully railed output with every value at –256, the logarithmic table output would be zero. The power of a full-rail sinusoid would be –3 dB; if every sample were 128, the power would be –6 dB, etc.

The AGC control logic 230 uses this total power estimate to keep the signal in-range at the A/D

35   converters 190-IP and 190-Q. If the signal power is determined to be out of range (but not saturating the A/D converters 190-IP and 190-Q), a coarse gain change will be made to put the signal back in range.

More specifically, if AGC control logic 230 detects the total measured power $adcpwr1$ (in the embodiment, within the range -63 - 0 dB) is greater than the maximum desired A/D converter signal size, the desired gain value $gaintarget$, which is a signal size that is set large enough so that quantization noise is small enough, but also small enough that ADC saturation is not an issue, including the size of the signal

5   and any potential blocker, is reduced in a course gain drop by the AGC control logic 230 of the equation

$$gaintarget = gaintarget + (coarsepwr\_const - adcpwr1) \qquad (2)$$

where $coarsepwr\_const$ is an additional gain for coarse gain drop (FIG. 4), e.g., -17 dB. This additional gain loss is used because the incoming signal may be too large to quantize but not large enough to trigger a quick drop as described in greater detail below -- for example, if the signal saturates occasionally but not

10   enough to trigger a quick drop. In such cases, it is useful to drop the gain by more than the $gaintarget$ value indicates, based on power measurements of a saturated waveform -- a very aggressive drop. Thus, the empirically determined $coarsepwr\_const$ value is added to increase the gain drop to more quickly converge on the desired signal size. The result is used to generate appropriate control signals for the amplifiers via the gain control generator 235.

15   If the total measured power $adcpwr1$ is less than the minimum desired A/D converter signal size, the desired gain value $gaintarget$ is increased by the AGC control logic 230 of the equation

$$gaintarget = gaintarget + (totalsizedesired - adcpwr1) \qquad (3)$$

where $totalsizedesired$ is the target A/D converter signal size during coarse gain changes, i.e., the desired size of the A/D converter output in the absence of a desired signal (FIG. 5) -- about -17 dB in the

20   preferred embodiment.

AGC Quick Drop Gain Control

        If the received signal is saturating the A/D converters 190-IP and 190-Q often, a precise power measurement may not be obtained; however, it is certain that the signal is well out of range. This

25   information can be used to quickly reduce the gain. More specifically, a saturation counter $adcsat$ is established by the AGC control logic 230 to count the number of saturations of either the I or Q A/D converter output samples. A pair of saturation thresholds $adcsat\_thrh$ and $adcsat\_thrl$, which can be changed by downloading a different threshold, are used to counter any possible lack of A/D converter range. Thus, a saturation will be detected if

30             $adcoutput \geq (adcsat\_thrh + 192) \qquad (4)$

or if

        $adcoutput \leq (adcsat\_thrl - 256) \qquad (5)$

where $adcsat\_thrh$ is a high threshold less than the maximum A/D converter output value which designates saturation on the high side of the A/D converter output, $adcsat\_thrl$ is a low threshold value

35   greater than the minimum A/D converter output value which designates saturation on the low side of the A/D converter output (FIG. 6) and the constant values are implementation-dependent. $adcsat\_thrh$ is set

to be slightly less than the maximum A/D converter output, while *adcsat_thrl* is set to be slightly higher than the minimum A/D converter output. This is useful because it allows signals that are close to saturation of, but do not actually saturate, the A/D converter to be classified as saturation signals for more flexibility. If the number of saturations of the A/D converter output samples during a sample window of

5   *adcsat_icount* cycles (preferably less than or equal to eight, the number of cycles in the quarter-symbol 802.11a measurement window) exceeds a saturation threshold amount *adcsat_thresh* a quick gain drop is instructed by the AGC control logic 230, and *gaintarget* is reduced by a predetermined amount *quick_drop*, e.g., a -30 dB change in gain. In the preferred embodiment, the *adcsat_thresh* is set for at a threshold of 12 saturations in an 8-cycle window (with saturations independently possible on I and Q

10   ADCs).

This technique may advantageously be implemented in the following way. After calibration or any gain change, an AGC settling time occurs. After that *adcpwr1* , the variable corresponding to the amount of measured power, is reset and an *acc_count* counter, preferably an eight-bit incremental counter cycling continuously during AGC operation, also is reset.

15   The following events will happen of the counter *acc_count*:

mod(*acc_count*, 16) = 0: reset *adcpwr1* accumulator

mod(*acc_count*, 16) = 1: clear reset on *adcpwr1* accumulator

mod(*acc_count*, 16) = 2: store *adcpwr1*

mod(*acc_count*, 16) ≤ *adcsat_icount* and *adcsat* = 1 (asserted when *set_thresh* saturations, e.g.

20   · eight saturations, have been counted), the saturation counter has exceeded *adcsat_thresh* and a quick gain drop should be executed. As shown, in the preferred embodiment, the *adcpwr1* values are computed every ·16 cycles, and the system looks for *adcsat* to be asserted prior to the first 4 bits of the counter registering a value greater than *adcsat_icount* (preferably 8).

25   <u>AGC Packet Detection</u>

Once the received signal is in-range, the AGC control logic 230 detects the presence of a desired packet. For this purpose, the AGC control logic 230 determines an in-band power estimation, uses the FIR filters 205-IP, 210-IP and 205-Q and 210-Q to reduce all adjacent and alternate blockers to 20 dB below the in-band signal power at 802.11a specified maximum levels, and compares *adcpwr1* and

30   *firpwr1* as described hereinafter. This is done to obtain information about whether quantized signal energy at the A/D converter 190-IP or 190-Q is in-band or out-of-band -- information which helps in finding the desired packets.

More specifically, consider the signal shown in FIG. 7A. Calculating the power of an A/D converter output as described above might determine that it has an overall power of, say, -12dBr, where

35   dBr is a measure of the RMS size of signals below the full rail signal size described above with reference to Equation (1). Passing through the second FIR 210-IP or 210-Q as shown in FIG. 7B, however, the signal loses most of its power and is reduced to a level of about -25 dBr -- a decrease of roughly 85%.

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Since most of the signal's power was blocked by the bandpass FIR 210-IP or 210-Q, it is presumed to be an out-of-band signal.

Referring to the signal shown in FIG. 8A, this signal too has an overall power of about -12BDr as measured at the A/D converter output. Passing through the second FIR 210-IP or 210-Q as shown in FIG. 8B, however, only reduces its power to approximately -15 dBr -- a decrease of only about 10%. Since most of the signal's power was passed by the bandpass FIR 210-IP or 210-Q, it is presumed to be an in-band signal.

With this understanding, the in-band power is calculated as the sum of instantaneous power measurements, preferably in a 32 sample, 0.8 μs window similar to the overall power calculation *adcpwr1* described above. *firpwr1* is the power based on the lowest of some number of samples that is less than the entire number of samples obtained, such as 28 out of 32 samples in the 32 sample window in detector 220. It is noted that the number of samples for *firpwr1* is greater than the number of samples for *adcpwr1* because *firpwr1* is being used for fine gain control, where precision is important, whereas *adcpwr1* is being used for coarse gain changes, where a slightly noisy power estimate will do. It is also noted that while for purposes of this in-band power calculation less than the entire number of samples is preferably used, that other post analog to digital converter processing that takes place using such samples will typically use all the samples obtained.

This less than the entire number of samples is used because during periods of interference, e.g., at symbol boundaries of the interferers, a temporary in-band power spike may occur due to high-frequency components of interferers at the symbol transition becoming in-band components in the desired band. This will artificially show up as a step in the in-band power. Windowing at the transmitter of the interferer, e.g., using a value which is half the previous value added to half the subsequent value at the symbol boundary, reduces this somewhat, as does lowpass filtering, so that the aggregate spectrum passes the necessary spectral mask. These instantaneous high frequency peaks, although lowered, can still exist. When an adjacent interferer is present, this temporary high frequency component in the interferer is actually in-band for the desired signal, so that the in-band power measurement when no desired signal is present can get a quick spike for a few samples, looking like an increase in the in-band power. To combat this, the lowest 28 of the 32 samples are used so this temporary spike is nulled out by not counting those values, and thresholds are adjusted accordingly to compensate for the reduced power measurement due to the missing four samples. Once a signal of interest is present, however, all samples are preferably used in creating the power measurement to make a detailed measurement. This second power measurement is called *firpwr_all.*Using the power information described above, desired signals can be found in two ways: strong signal detection and weak signal detection. Strong signal detection will be described first.

Strong Signal Detection

Any time a coarse gain drop or quick gain drop as described above occurs, a flag *strongsignal* is set by the AGC control logic 230. This flag remains high until the signal is determined to be in range at

the A/D converter 190-IP or 190-Q, and the algorithm proceeds to make a *firpwr1* measurement as described above. At this point, *flag_relpwr* is calculated as

$$flag\_relpwr = set \ if \ (firpwr1 > relpwr + adcpwr) \tag{6}$$

(where *relpwr* is an empirical thresholding variable related to the absolute digital size of the in-band

5   signal relative to the absolute total digital signal at the A/D converter 190-IP or 190-Q), thus attempting to see that most of the computed power is in-band. If *flag_relpwr* is high and *strongsignal* is high, then a new, very strong in-band signal has appeared. In this way, the embodiment permits examination of an oversampled incoming signal having digitized frequencies beyond a desired frequency range due to oversampling, and determine whether most of its power is in-band before determining that a desired signal

10   has been found.

Thus, when *flag_relpwr* is high and *strongsignal* is high, the *signal_found* flag is asserted, a fine gain change is made as described below and the AGC process is completed once the number of consecutive gain changes is equal to or greater than the minimum number of gain changes deemed to constitute a successful AGC operation, i.e., when there have been enough gain changes to ensure a full

15   programmable amplifier ramp-up when the system is turned on.

Weak Signal Detection

In weak signal detection, the normalized self-correlation of short sequences as defined below is measured to look for anything in-band with a periodicity of 0.8 μs in the preferred embodiment. This is a

20   two-step process performed concurrently with the above-described strong signal detection process. First, the system waits for the normalized self-correlation as measured by the self-correlation processor 225 to exceed a first normalized self-correlation magnitude threshold value *ml thres*.

The self-correlation processor 225 preferably measures self-correlation of 802.11a packets by taking 32 samples in a short training symbol at the beginning of a packet and comparing each of the

25   samples to a corresponding sample from the preceding short training symbol. More specifically, the self-correlation of an A/D converter stream *adcoutput* is given by

$$self\_corr = \frac{\left[\sum adcoutput[n] \bullet conj(adcoutput[n-32])\right]^2}{\sum adcoutput[n]^2} \tag{7}$$

where the denominator is a normalization factor. One can see that the numerator will be relatively high

30   when x[n] and x[n-32] are identical and relatively low when, e.g., they are uncorrelated. Thus, this measure can serve as a good indicator of self-correlation.

Detecting when the self-correlation output exceeds *ml thres* can thus detect the existence of an incoming packet; however, it would also detect interferers, since they can have structures that can also self-correlate. For this reason, the embodiment advantageously employs another test. Once the

35   normalized self-correlation exceeds *ml thres*, the system enters a loop and for *ml count_max* cycles counts

in a variable *m1tally* the number of times the normalized self-correlation exceeds a second normalized self-correlation magnitude threshold value *m2thres*, where *m2thres* is less than or equal to *m1thres*. If *m1tally* > *m2count_thr* , a threshold of the count of normalized self-correlation > *m2thres*, before *m1count_max* (a window length for the self-correlation count) cycles have elapsed, weak signal detection

5   may be detected.

As noted above, the windowing technique based on *m1count_max* is used because both interferers and noise may have a self-correlation that momentarily exceeds a threshold, but the chances of this occurring diminish when windows of samples obtained over consecutive periods of time are used. For example, a subsequent window will contain many of the same samples as the previous window, but the

10   previous window will not contain the most recent sample from the subsequent window, and the subsequent window will not contain the oldest sample from the previous window. Thus, for example, if two 802.11a symbols in adjacent channels are sent, such that they are separated in frequency by 20MHz, the last 0.8 µs of the first symbol will exactly match the next 0.8 µs guard period of the next symbol, creating self-correlation, but this spike will rapidly fade, in comparison with a preamble where a flat

15   normalized self-correlation result is expected for the preamble duration.

Thus, the embodiment provides a way of performing a two-threshold windowing process on a self-correlation measurement. One threshold is used to determine that a signal may be present in-band, and the number of times a second threshold is exceeded in different windows of offset samples is counted to further determine if that in-band signal is a desired signal. This is done to combat temporary

20   correlation of thermal noise as well as to combat self-correlation during the data segment of an interferer.

Additionally, for further robustness against thermal noise and interferers, the embodiment preferably requires that to enable a weak signal detection result, a potential detected packet must increase the in-band signal power by at least a certain amount and that the increase be at least proportional to any increase in the total signal power, the signal power being of at least a certain minimum size. This

25   provides extra sensitivity when a new in-band signal comes in below an interferer or near the noise floor, thus not triggering strong signal detection but worthy of a look for weak signal detection.

At least three things may stop weak signal detection from occurring once *m1tally* > *m1thresh*. First, if *ycOK* = 0, weak signal detection will not occur. *ycOK* is a decrementing counter that is reset to *ycOKmax* (in the embodiment, four) to enable weak signal detection if it is determined that an increase in

30   the in-band signal of a certain size (*flag_firstep*) and at least proportional to any increase in the total power (*flag_relstep*) with the measured *firpwr1* of at least a certain minimum size (*flag_firpwr*), then it is possible that a new in-band signal has come in below an interferer or near the noise floor, thus not triggering strong signal detection but worthy of a look for weak signal detection. To ensure that such recognition occurs within a limited period of time, the above must happen while *ycOK* > 0 if it happens at

35   all. To perform these step calculations, old values of *firpwr1* and *adcpwr* are stored as *firpwr{2-4}* and *adcpwr{2-4}*. Enough values are stored so that if the signal is detected during a programmable amplifier ramp, enough difference will exist between the first and last measurements to exceed the given threshold.

Another reason why weak signal detection might not occur is because *gc_count* is greater than zero. *gc_count* measures the time since the last gain change in short symbol increments, getting decremented by the AGC control logic 230 for every valid *firpwr1* measurement from its starting value of three after a gain change. The idea is that after a gain change, there is a minimum amount of time until a self-correlation is valid.

Finally, weak signal detection will not occur if the signal has already been found with another method, since then there is no need to find it using weak signal detection.

AGC Packet Detection -- DC Offset Elimination

The above double threshold arrangement is successful in reducing false packet detects on interferers during weak signal detection; however, it is not particularly successful in preventing false detection with respect to DC signals, which always self-correlate. There is typically a small DC component at the output of the A/D converter 190, so the embodiment uses a two-tap DC notch filter as a leaky bucket filter -- more specifically, a two-tap IIR filter having a transfer curve of the form

$$y[n] = \frac{\alpha - 1}{\alpha} y[n-1] + \frac{1}{\alpha} x[n] \qquad (8)$$

where x is the input signal, y is the output signal and α is a filter parameter (in this case, 32) -- which uses an estimate of the DC level provided by the AGC logic control 230 to cancel the DC component out. The AGC control logic 230 obtains this level from a lookup table based on current gain settings.

AGC Completion Processing

Once the signal is found via either strong signal detection or weak signal detection, fine gain changes will be made, in the preferred embodiment if *consec_gainchanges < min_gainchanges*. And in the preferred embodiment, every fine gain change will be made based upon the equation

$$gain\_change = adc\_desired\_size - firpwr1\_all \qquad (9)$$

consec_gainchanges begins at zero for strong signal detection and two for weak signal detection, since it is meant to be a coarse measure of time spent in the AGC, and it takes approximately two gain change times to perform a windowed self-correlation. It is incremented every coarse and fine gain change. It is reset when no gain change is made and strong signal detection does not decide that a signal is present. This feature is meant to ensure that a minimum amount of time is spent in the AGC, for either more precise gain or to be sure the gain is set after the PA is done ramping.

The preferred embodiments described above have been presented for purposes of explanation only, and the present invention should not be construed to be so limited. Variations on the present invention will become readily apparent to those skilled in the art after reading this description, and the present invention and appended claims are intended to encompass such variations as well.

WHAT IS CLAIMED IS:

1.   A method of estimating whether a received strong signal is an in-band signal based upon power estimates, the method comprising the steps of:

inputting the received strong signal;

measuring the power of the received strong signal;

providing the received strong signal to a filter section;

using the filter section to pass frequency components of the received strong signal within a desired band of frequencies to obtain a filtered signal;

measuring the power of the filtered signal and

comparing the power measurement of the received strong signal to the power measurement of the filtered signal to obtain an indication that the received signal is estimated as being in-band.

2.   The method of claim 1, wherein measuring the power of the received strong signal and measuring the power of the filtered signal are performed by taking samples within windows of the received strong signal and the filtered signal, respectively.

3.   The method of claim 2, wherein extreme samples in the measurement of the received strong signal and in the measurement of the filtered signal are not used in the respective measurements.

4.   The method of claim 3, wherein highest magnitude samples in the measurement of the received strong signal and in the measurement of the filtered signal are not used in the respective measurements.

5.   The method of claim 4 wherein prior to the step of measuring the power of the received strong signal there is included the step of removing DC offset from the input signal.

6.   The method of claim 4 wherein the step of measuring the power of the received strong signal uses a different number of signal samples than the step of measuring the power of the filtered signal.

7.   The method of claim 4 wherein the received signal power measurement is made based upon less than a received whole short training symbol.

8.   The method of claim 4 wherein the received signal power measurement is made based on half of a period of a slowest frequency sinusoid that exists within a training symbol containing a plurality of sinusoids, with each of the plurality of sinusoids having a frequency that is an integer multiple of the slowest frequency sinusoid.

9.   The method of claim 2 wherein prior to the step of measuring the power of the received strong signal there is included the step of removing DC offset from the input signal.

10.   The method of claim 2 wherein the step of measuring the power of the received strong signal uses a different number of signal samples than the step of measuring the power of the filtered signal.

11. The method of claim 1, wherein comparing the power measurements of the received strong signal and the filtered signal includes determining whether the filtered signal power measurement is at least a certain portion of the received signal power measurement.

12. The method of claim 1 wherein prior to the step of measuring the power of the received strong signal there is included the step of removing DC offset from the input signal.

13. The method of claim 1, further including the step of determining that the received strong signal is a desired signal after the indication has been provided.

14. The method of claim 1 wherein the received signal power measurement is performed on less than a whole short training symbol.

15. The method of claim 14 wherein the received signal power measurement is performed on about one half of a received whole short training symbol.

16. A method of estimating whether an input signal is an in-band signal, the method comprising the steps of:

inputting the input signal;

converting the input signal to a received digital signal using an analog to digital converter;

determining whether the received digital signal is saturating the analog to digital converter and if so identifying the digital signal as a strong signal type;

measuring the power of the received digital signal;

determining whether the power of the received digital signal is greater than a desired level and if so identifying the received digital signal as the strong signal type;

providing the received digital signal to a filter section;

using the filter section to pass frequency components of the received digital signal within a desired band of frequencies to obtain a filtered signal;

measuring the power of the filtered signal and

comparing the power measurement of the received digital signal to the power measurement of the filtered digital signal to obtain an indication that the received signal is an in-band signal type; and

determining that the received digital signal is an in-band signal if the received digital signal is indicated as being of the in-band type and is identified as being of the strong signal type.

17. The method of claim 16 further including the steps of:

reducing a gain provided by an automatic gain control circuit to an automatic gain control amplification section if saturation is determined; and

reducing a gain provided by the automatic gain control circuit to the automatic gain control amplification section if the power of the received digital signal is greater than the desired level.

18. The method of claim 16, wherein measuring the power of the received digial digital signal and measuring the power of the filtered signal are performed by taking samples within windows of the received digital signal and the filtered signal, respectively.

19.   The method of claim 18, wherein extreme samples in the measurement of the received digital signal and in the measurement of the filtered signal are not used in the respective measurements.

20.   The method of claim 19, wherein highest magnitude samples in the measurement of the received digital signal and in the measurement of the filtered signal are not used in the respective measurements.

21.   The method of claim 20 wherein prior to the step of measuring the power of the received digital signal there is included the step of removing DC offset from the input signal.

22.   The method of claim 20 wherein the step of measuring the power of the received digital signal uses a different number of signal samples than the step of measuring the power of the filtered signal.

23.   The method of claim 20 wherein the received digital signal power measurement is performed on less than a received whole short training symbol.

24.   The method of claim 23 wherein the received digital signal power measurement is performed on about one half of a received whole short training symbol.

25.   The method of claim 18 wherein prior to the step of measuring the power of the received digital signal there is included the step of removing DC offset from the input signal.

26.   The method of claim 18 wherein the step of measuring the power of the received digital signal uses a different number of signal samples than the step of measuring the power of the filtered signal.

27.   The method of claim 18, wherein comparing the power measurements of the received strong signal and the filtered signal includes determining whether the filtered signal power measurement is at least a certain portion of the received signal power measurement.

28.   The method of claim 16 wherein prior to the step of measuring the power of the received strong signal there is included the step of removing DC offset from the input signal.

29.   The method of claim 16 wherein the received signal power measurement is determined base upon less than a whole short training symbol.

30.   The method of claim 29 wherein the received signal power measurement is determined based upon about one half of a received whole short training symbol.

31.   The method of claim 16 further including the step of making a fine automatic gain control adjustment if it was determined that an in-band signal exists.

32.   A method of determining that a received digital signal of the strong signal type exists within an input signal including the steps of:

            converting the input signal to a received digital signal using an analog to digital converter;

            measuring the power of the received digital signal; and

            determining whether the power of the received digital signal is greater than a desired level and if so identifying the received digital signal as the strong signal type.

33.   The method of claim 32 further including the step of

reducing a gain provided by an automatic gain control circuit to an automatic gain control amplification section if the power of the received digital signal is greater than the desired level.

34.   The method of claim 33 wherein the step of reducing the gain reduces the gain by an amount that is based upon the determined power and a predetermined gain target value.

35.   The method of claim 32 further including the steps of:

determining whether the received digital signal saturates the analog to digital converter and if so identifying the digital signal as the strong signal type.

36.   The method of claim 35 further including the steps of:

determining whether the received digital signal saturates the analog to digital converter; and

reducing a gain provided by an automatic gain control circuit to an automatic gain control amplification section if the received digital signal is determined to saturate the analog to digital converter.

37.   The method of claim 36 wherein the step of reducing the gain reduces the gain a predetermined amount.

38.   The method of claim 35 wherein the step of determining whether the received digital signal saturates the analog to digital converter includes the steps of:

counting a number of times that a plurality of samples of the received digital signal exceeded the predetermined saturation threshold; and

comparing the number of times with a predetermined saturation count threshold, such that when the predetermined saturation threshold is exceeded, the received digital signal is determined to saturate the analog to digital converter.

39.   A system for detecting in-band signals, the system comprising:

a filter section for filtering a received digital signal to pass frequency components of the received digital signal within a desired band of frequencies to obtain a filtered signal;

a power detector for measuring power of the filtered signal and for measuring power of the received digital signal; and

control logic for, based on the measured power of the received digital signal and the filtered signal, determining whether the received signal is an in-band signal.

40.   The system of claim 39, wherein the filter section includes a finite impulse response filter.

41.   The system of claim 39, wherein the filter section includes a decimation filter.

42.   The system of claim 39, wherein the filter section includes a low-pass filter.

43.   The system of claim 36, wherein the power detector includes separate power detectors for measuring the received digital signal and the filtered signal.

44.   The system of claim 43, wherein each of the power detectors includes a sampler configured to take samples of its respective signal within windows thereof.

45.   The system of claim 43 wherein each of the power detectors does not use highest magnitude samples in the measurement of its respective signal.

46.   The system of claim 39, wherein the filtered signal power measurement uses at least certain signal samples from the received signal power measurement.

47.   The system of claim 39 further including a DC offset control unit for removing DC offset from the input signal.

48.   The system of claim 39 wherein the control logic includes:

means for determining whether the power of the received digital signal is greater than a desired level and if so identifying the received digital signal as the strong signal type.

49.   The system of claim 48 further including:

means for reducing a gain provided by an automatic gain control circuit to an automatic gain control amplification section if the power of the received digital signal is greater than the desired level.

50.   The system of claim 49 wherein the means for reducing the gain reduces the gain by an amount that is based upon the determined power and a predetermined gain target value if the power of the received digital signal is greater than the desired level.

51.   The system of claim 49 further including:

means for determining whether the received digital signal saturates the analog to digital converter and if so identifying the digital signal as the strong signal type.

52.   The system of claim 51 wherein the means for determining includes

means for counting a number of times that a plurality of samples of the received digital signal exceeded a predetermined saturation threshold; and

means for comparing the number of times with a predetermined saturation count threshold, such that when the predetermined saturation threshold is exceeded, the received digital signal is determined to saturate the analog to digital converter.

53.   The system of claim 51 further including:

means for reducing the gain provided by the automatic gain control circuit to the automatic gain control amplification section if the received digital signal is determined to saturate the analog to digital converter.

54.   The method of claim 36 wherein the means for reducing the gain reduces the gain a predetermined amount if the received digital signal is determined to saturate the analog to digital converter.

55.   A method of determining that a received digital signal of the strong signal type exists within an input signal including the steps of:

converting the input signal to a received digital signal using an analog to digital converter;

determining whether the received digital signal saturates the analog to digital converter; and

reducing a gain provided by an automatic gain control circuit to an automatic gain control amplification section if the received digital signal is determined to saturate the analog to digital converter.

56. The method of claim 55 wherein the step of reducing the gain reduces the gain a predetermined amount.

57. The method of claim 55 wherein the step of determining whether the received digital signal saturates the analog to digital converter includes the steps of:

counting a number of times that a plurality of samples of the received digital signal exceeded the predetermined saturation threshold; and

comparing the number of times with a predetermined saturation count threshold, such that when the predetermined saturation threshold is exceeded, the received digital signal is determined to saturate the analog to digital converter.

58. A method of performing signal detection, the method comprising the steps of:

obtaining a self-correlation measurement of a received signal;

determining whether the self-correlation measurement exceeds a first threshold value;

when the self-correlation measurement exceeds the first threshold value, determining how many times subsequently obtained self-correlation measurements of the received signal exceed a second threshold value during a given time period;

when a count threshold is exceeded by the number of times the subsequent measurements exceed the second threshold value, determining that the received signal possibly includes a desired signal.

59. The method of claim 58, wherein obtaining the self-correlation measurement comprises:

taking multiple samples of the received signal;

summing the product of each sample and the complex conjugate of one of a plurality of previously obtained samples taken a predetermined amount of time earlier; and

normalizing the sum thus obtained.

60. The method of claim 59, further comprising:

determining an in-band power level of the in-band components of the received signal using the multiple samples of the received signal;

determining a received signal power level of the received signal using the multiple samples of the received signal;

comparing the received signal power level and the in-band power level; and

when the received signal power level possibly includes a desired signal, determining that the received signal does include a desired signal if an increase in the in-band power level is at least proportionate to any increase in the received signal power level.

61. The method of claim 60 wherein the step of identifying the in-band power level uses most of but less than all of those samples identified as being in-band components.

62. The method of claim 61 wherein samples used of those samples identified as being in-band components have a lower power level than unused samples of those samples identified as being in-band components.

63. The method of claim 61 wherein 32 samples are identified as being in-band components and 28 of the 32 samples are used to determine the in-band power level.

64.   The method of claim 60 wherein the step of obtaining the self-correlation measurement includes the step of removing DC offset from the received signal.

65.   The method of claim 58, further comprising the steps of:

determining a power level of the received signal;

determining an in-band power level of in-band components of the received signal;

comparing the power level of the received signal and the in-band power level of the in-band components of the received signal; and

when the received signal possibly includes a desired signal, determining that the received signal does include a desired signal if an increase in the in-band power level is at least proportionate to any increase in the power level of the received signal.

66.   The method of claim 65 wherein the step of obtaining the self-correlation measurement includes the step of removing DC offset from the received signal.

67.   The method of claim 58, further comprising:

determining an in-band power level of in-band components of the received signal; and

when the received signal possibly includes a desired signal, determining that the received signal does include a desired signal if the in-band power level is at least a minimum size.

68.   The method of claim 67 wherein the step of determining the in-band power level uses most of but less than all samples identified as being in-band components.

69.   The method of claim 68 wherein samples used of those samples identified as being in-band components have a lower power level than unused samples of those samples identified as being in-band components.

70.   The method of claim 68 wherein 32 samples are identified as being in-band components and 28 of the 32 samples are used to determine the in-band power level.

71.   The method of claim 68 wherein the step of obtaining the self-correlation measurement includes the step of removing DC offset from the received signal.

72.   The method of claim 67 wherein the step of obtaining the self-correlation measurement includes the step of removing DC offset from the received signal.

73.   The method of claim 58 wherein the step of obtaining the self-correlation measurement includes the step of removing DC offset from the received signal.

74.   A system for detecting a desired signal, the system comprising:

a self-correlation device for performing a self-correlation measurement of a received signal; and

control logic configured to:

determine whether the self-correlation measurement exceeds a first threshold value,

when the self-correlation measurement exceeds the first threshold value, determining how many times subsequently obtained self-correlation measurements of the received signal exceed a second threshold value during a given time period, and

when a predetermined count value is exceeded by the number of times the subsequent measurements exceed the second threshold value, determining that the received signal possibly includes a desired signal.

75.   A method for detecting a desired signal, the method comprising the steps of:

measuring a power level of a received signal;

filtering the received signal to generate a filtered signal consisting substantially of components of the received signal that are within a frequency range of a desired signal;

measuring another power level of the filtered signal;

using the power level of the received signal and another power level of the filtered signal to perform a strong signal detection procedure to detect a strong desired signal in the received signal; and

using the power level of the received signal and the another power level of the filtered signal to perform a weak signal detection procedure to detect a weak desired signal in the received signal.

76.   The method of claim 75 further including the step of removing DC offset from the received signal prior to the step of measuring the power level of the received signal.

77.   A system for detecting a desired signal in an automatic gain control, comprising:

a power detector for measuring power of an input signal at a plurality of times, and thereby the power of a received signal;

a comparison circuit for comparing the power of the input signal at various times to determine the presence of the received signal;

a filter to pass substantially only components of the received signal that are within a frequency range of a desired signal, thereby obtaining a filtered signal;

a power detector to measure another power level of the filtered signal; and

control logic, wherein the control logic uses the power level and the another power level to perform a strong signal detection to detect a strong desired signal in the received signal and to perform a weak signal detection to detect a weak desired signal in the received signal.

78.   A method of performing signal detection, the method comprising:

obtaining self-correlation measurements of a received signal; and

determining whether the received signal may be a desired signal by operating upon the self-correlation measurements using a plurality of threshold values.

79.   The method of claim 78 wherein certain of the self-correlation measurements are operated upon with a first threshold value and other of the self-correlation measurements are operated upon with a second threshold value.

80.   The method of claim 79 wherein the second threshold value is the same as the first threshold value.

81.   The method of claim 79 wherein the second threshold value is lower than the first threshold value.

82.   The method of claim 78, wherein obtaining at least one of the self-correlation measurements comprise:

taking multiple samples of the received signal;

summing the product of each sample and the complex conjugate of one of a plurality of previously obtained samples taken a predetermined amount of time earlier; and

normalizing the sum thus obtained.

83.   The method of claim 82, further comprising:

determining an in-band power level of the in-band components of the received signal using the multiple samples of the received signal;

determining a received signal power level of the received signal using the multiple samples of the received signal;

comparing the received signal power level and the in-band power level; and

when the received signal power level possibly includes a desired signal, determining that the received signal does include a desired signal if an increase in the in-band power level is at least proportionate to any increase in the received signal power level.

84.   The method of claim 83 wherein the step of identifying the in-band power level uses most of but less than all of those samples identified as being in-band components.

85.   The method of claim 84 wherein samples used of those samples identified as being in-band components have a lower power level than unused samples of those samples identified as being in-band components.

86.   The method of claim 84 wherein 32 samples are identified as being in-band components and 28 of the 32 samples are used to determine the in-band power level.

87.   The method of claim 83 wherein the step of obtaining the self-correlation measurements includes the step of removing DC offset from the received signal.

88.   The method of claim 78, further comprising:

determining a power level of the received signal;

determining an in-band power level of in-band components of the received signal;

comparing the power level of the received signal and the in-band power level of the in-band components of the received signal; and

when the received signal possibly includes a desired signal, determining that the received signal does include a desired signal if an increase in the in-band power level is at least proportionate to any increase in the power level of the received signal.

89.   The method of claim 88 wherein the step of obtaining the self-correlation measurement includes the step of removing DC offset from the received signal.

90.   The method of claim 78, further comprising:

determining an in-band power level of in-band components of the received signal; and

when the received signal possibly includes a desired signal, determining that the received signal does include a desired signal if the in-band power level is at least a minimum size.

91.   The method of claim 90 wherein the step of determining the in-band power level uses most of but less than all samples identified as being in-band components.

92.   The method of claim 91 wherein samples used of those samples identified as being in-band components have a lower power level than unused samples of those samples identified as being in-band components.

93.   The method of claim 91 wherein 32 samples are identified as being in-band components and 28 of the 32 samples are used to determine the in-band power level.

94.   The method of claim 91 wherein the step of obtaining the self-correlation measurement includes the step of removing DC offset from the received signal.

95.   The method of claim 90 wherein the step of obtaining the self-correlation measurement includes the step of removing DC offset from the received signal.

96.   The method of claim 78 wherein the step of obtaining the self-correlation measurement includes the step of removing DC offset from the received signal.

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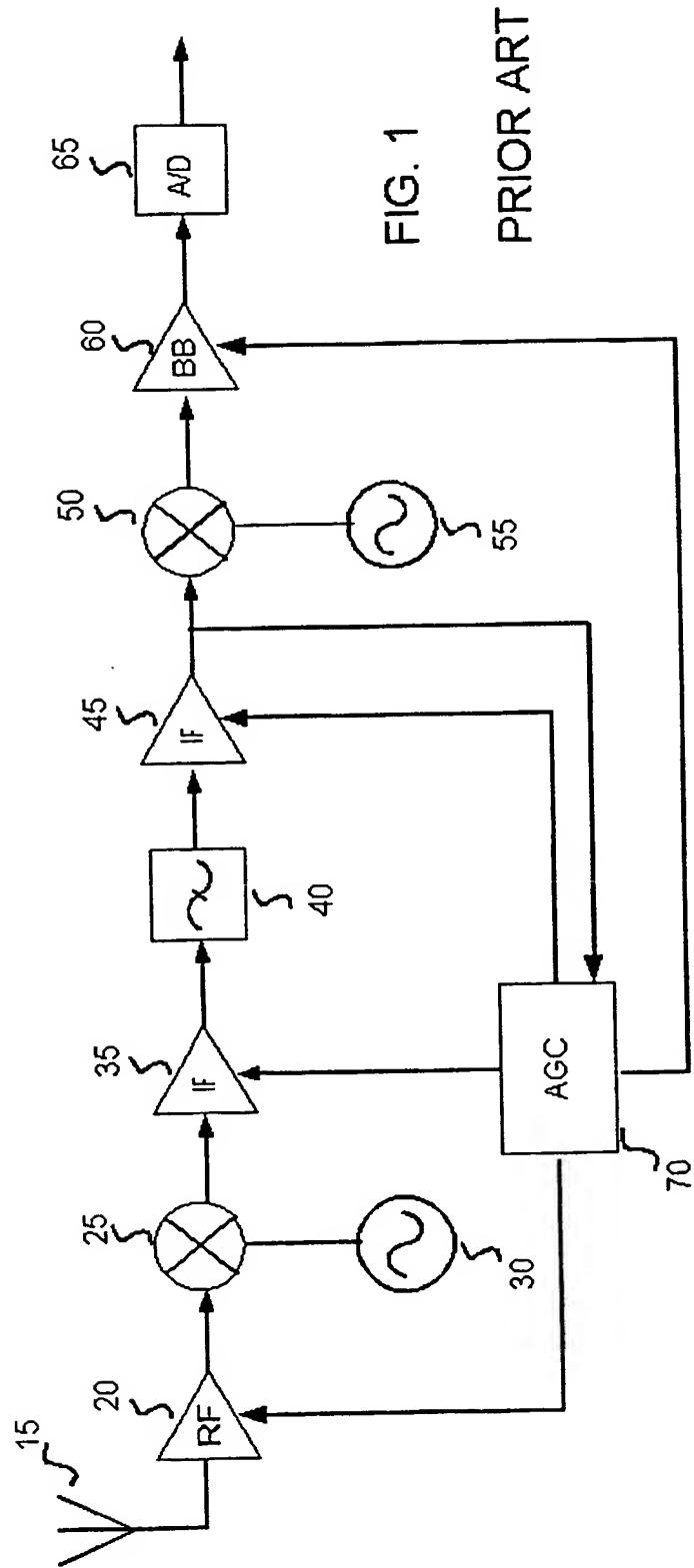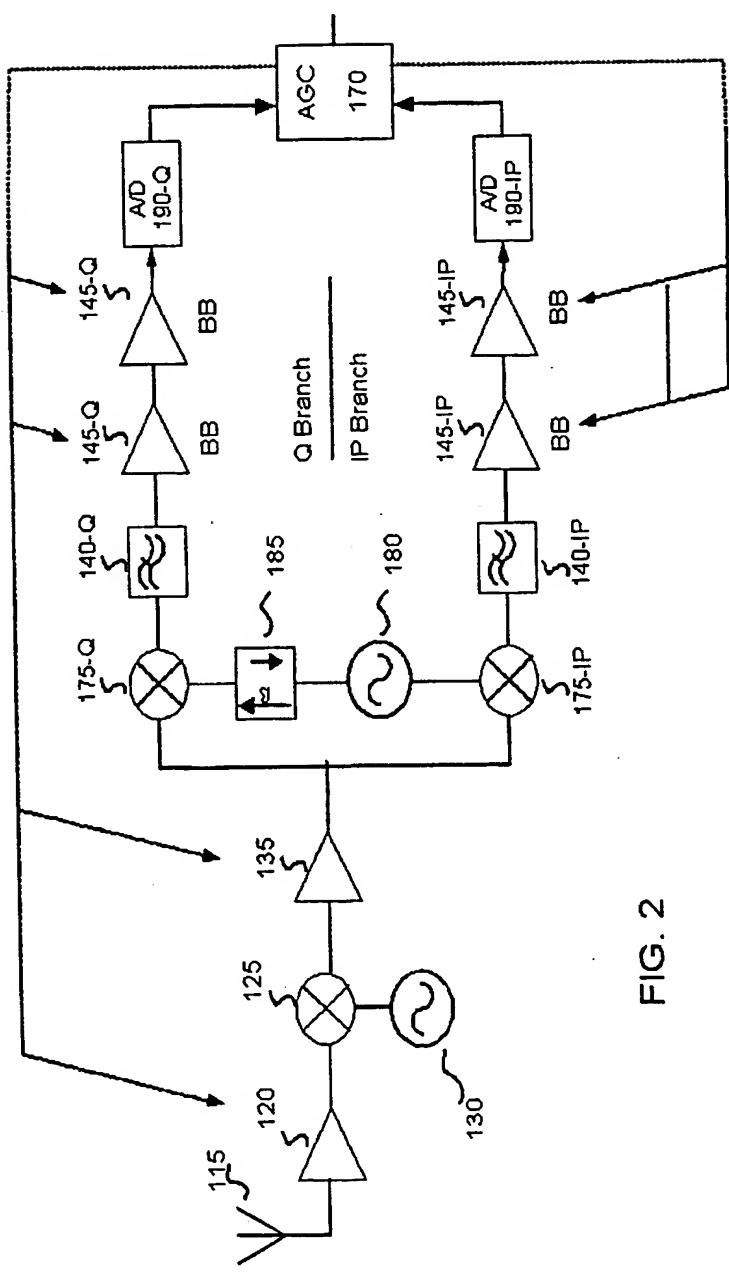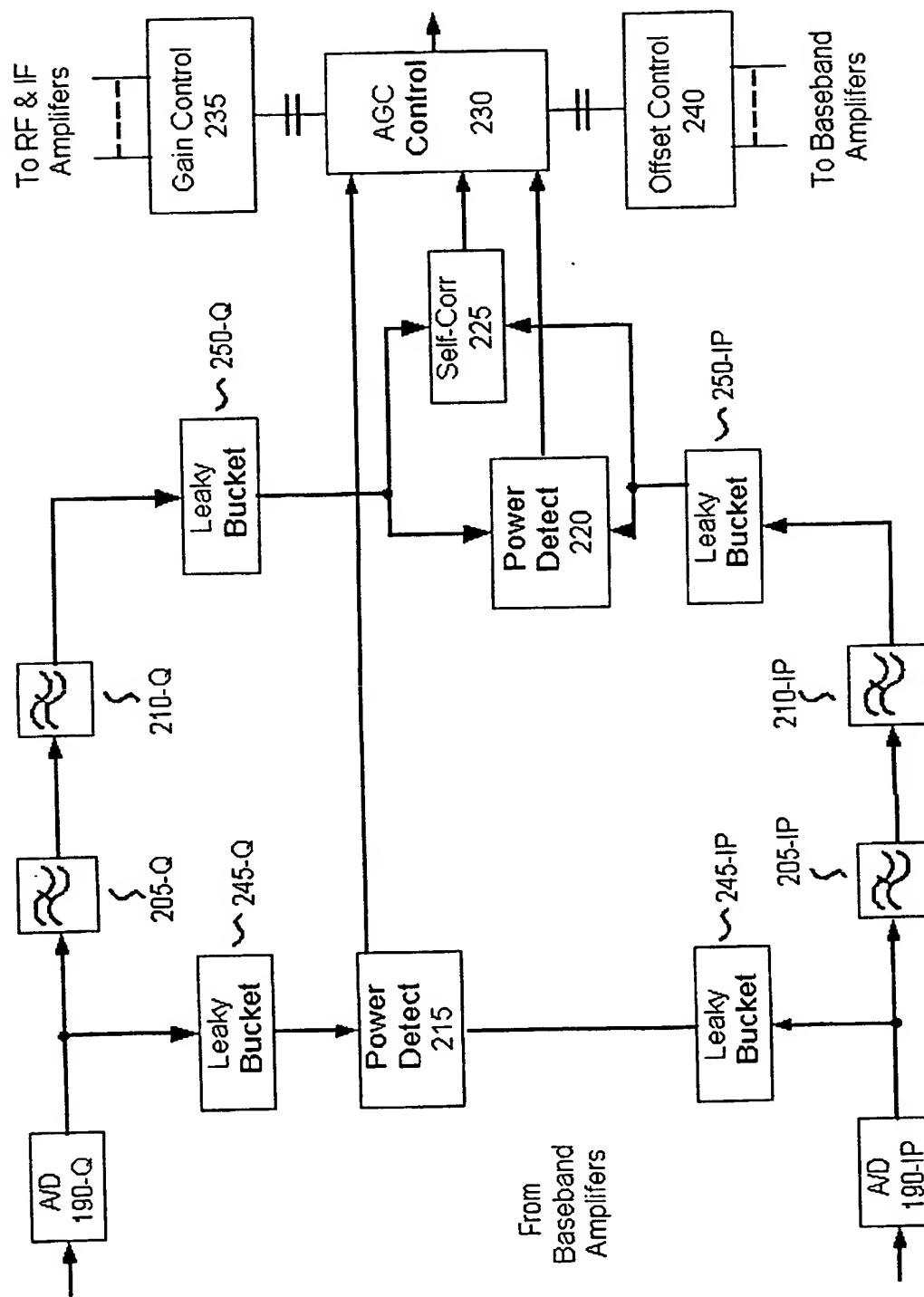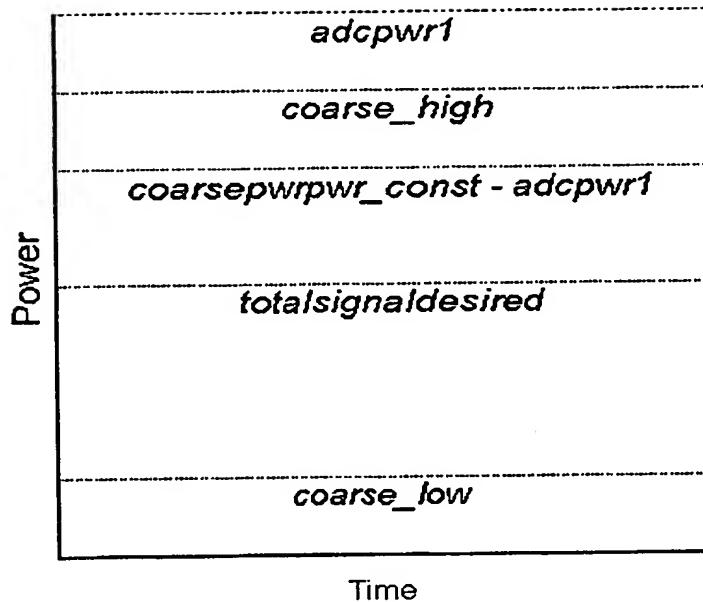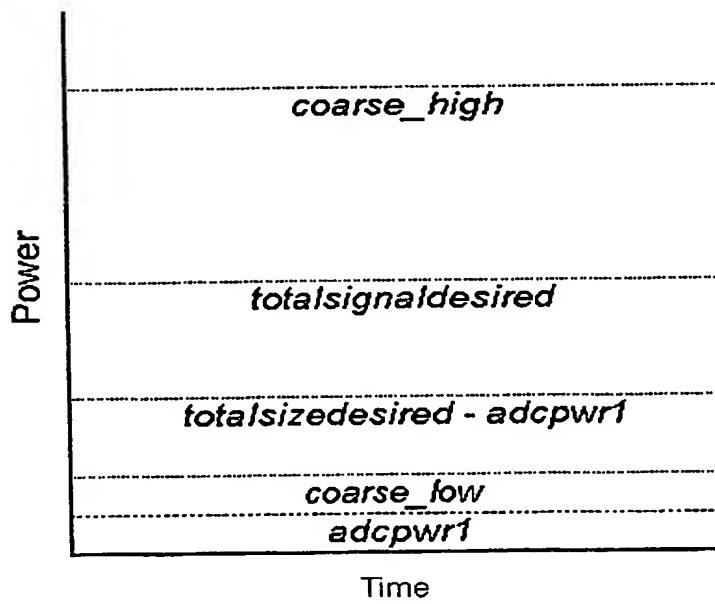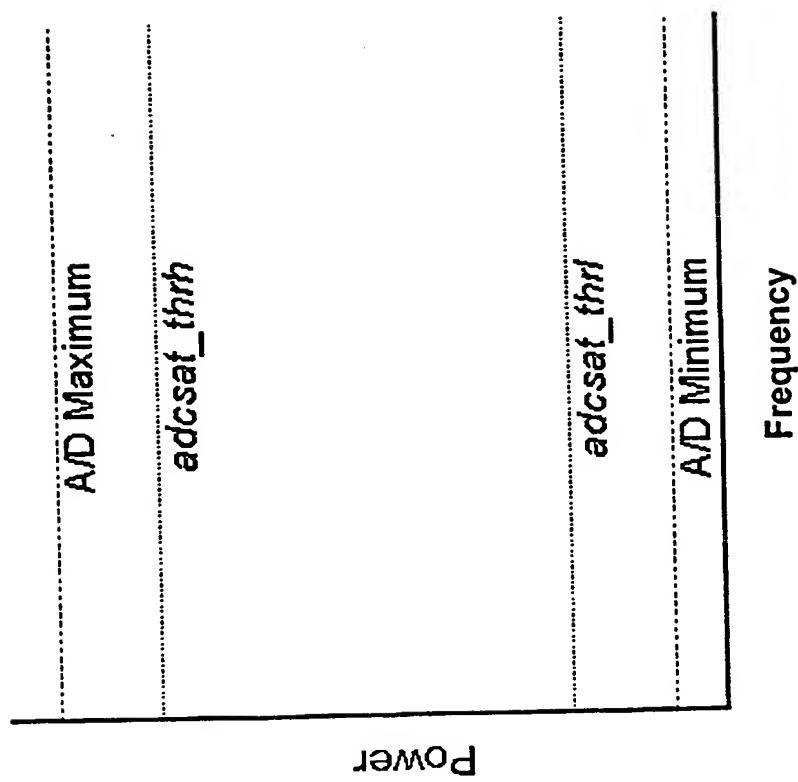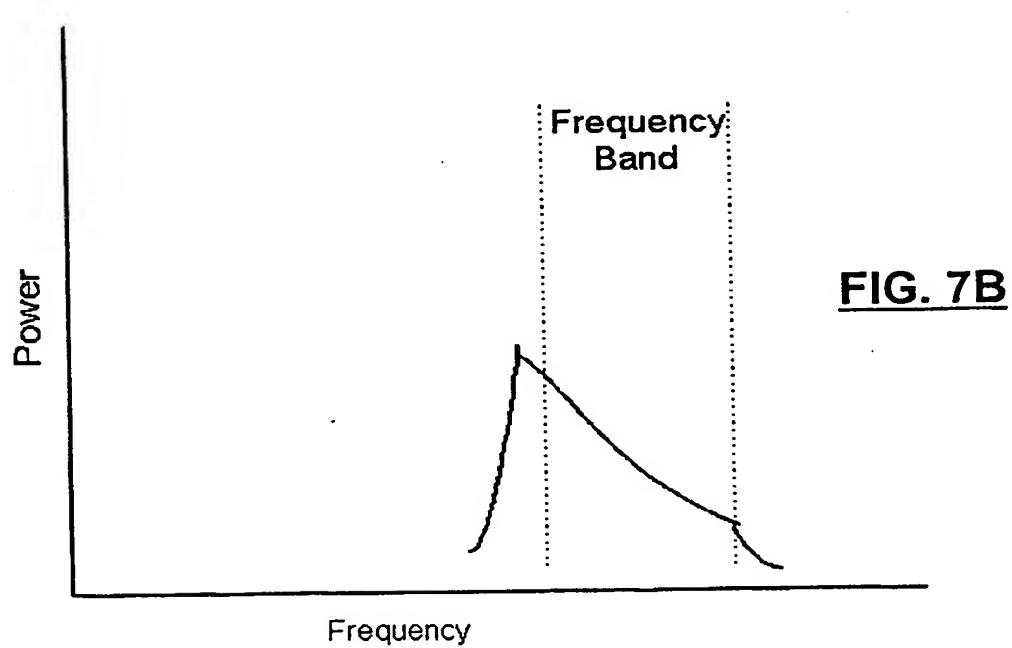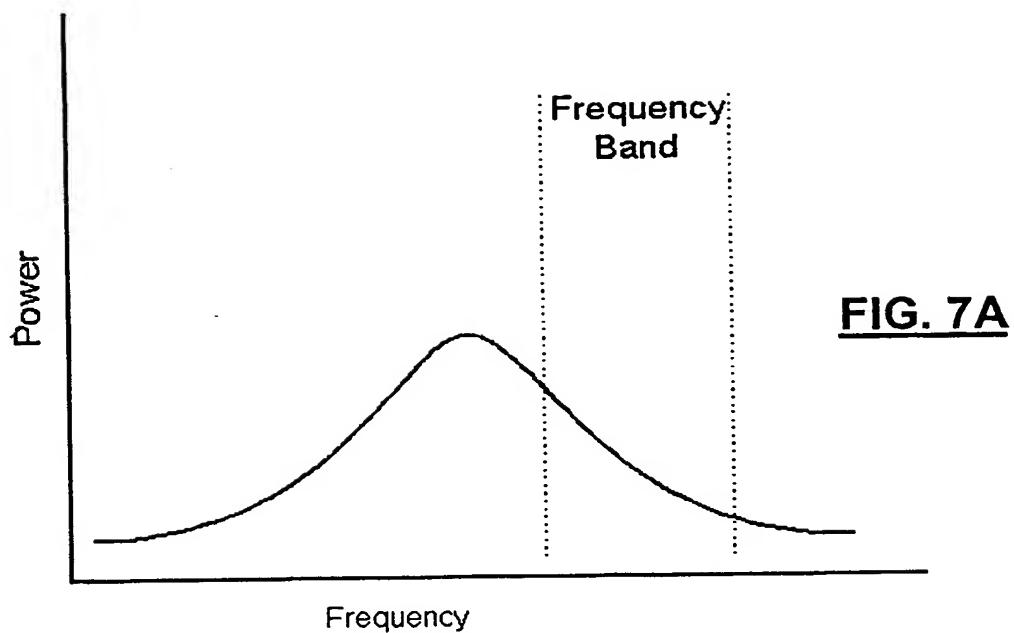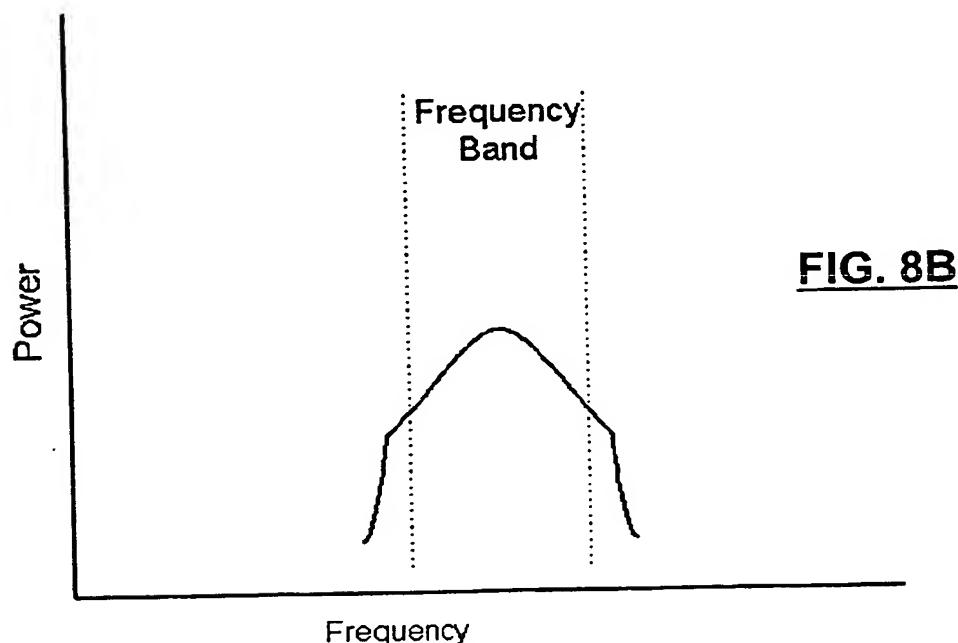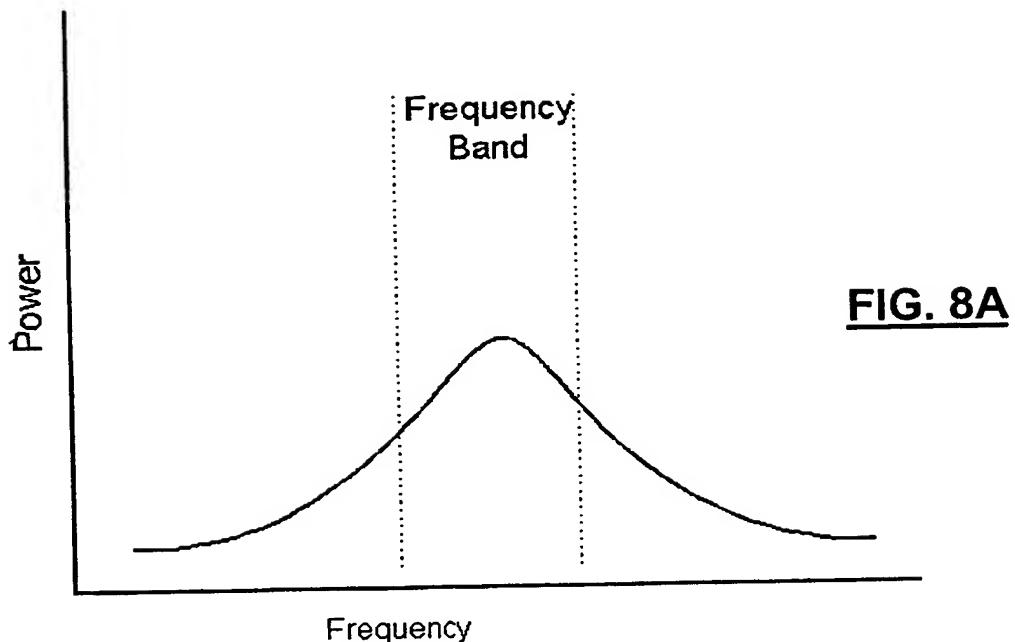
FIG. 1

PRIOR ART

FIG. 2

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FIG. 3

adcpwr1

coarse_high

coarsepwrpwr_const - adcpwr1

totalsignaldesired

coarse_low

Time

FIG. 4

coarse_high

totalsignaldesired

totalsizedesired - adcpwr1

coarse_low

adcpwr1

Time

FIG. 5

FIG. 6

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Frequency Band

Power

Frequency

FIG. 7A

Frequency Band

Power

Frequency

FIG. 7B

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FIG. 8A

FIG. 8B

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(54) Title: SELF-CORRELATION DETECTION AND IN-BAND AND OUT-OF-BAND SIGNAL DETECTION FOR AUTOMATIC GAIN CALIBRATION SYSTEMS

(57) Abstract: An embodiment of the present invention provides an automatic gain control system for a wireless receiver that quickly differentiates desired in-band signals from high power out-of-band signals that overlap into the target band. The system measures power before and after passing a received signal through a pair of finite impulse response filteres (205-IP), (210-IP), (205-Q), (210-Q) and (220) that largely restrict the signal's power to that which is in-band. By comprising the in-band energy of the received signal after filtering to the total signal energy prior to filtering (215), it is possible to determine whether a new in-band signal has arrived. The presence of this new in-band signal is then verified by a multi-threshold comparison of the normalized self-correlation (225) to verify the presence of a new, desired in-band signal.

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International application No.

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A.   CLASSIFICATION OF SUBJECT MATTER

IPC(7)   :   H04B 17/00, 1/06, 7/00
US CL   :   455/232.1, 234.1, 234.2, 226.1, 226.2, 296; 375/224, 345, 343

According to International Patent Classification (IPC) or to both national classification and IPC

B.   FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EAST

C.   DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,999,561 A (NADEN et al.) 07 December 1999 (07.12.1999), ALL	1-57 and 75-77
A	US 6,134,430 A (YOUNIS et al.) 17 October 2000 (17.10.2000), ALL	1-57 and 75-77
A,P	US 6,324,387 B1 (KAMGAR et al.) 27 November 2001 (27.11.2001), ALL	1-57 and 75-77
A	US 6,219,334 B1 (SATO et al.) 17 April 2001 (17.04.2001), ALL	58-74 and 78-96
A	US 6,067,293 A (SHOJI) 23 May 2000 (23.05.2000), ALL	58-74 and 78-96

☐ Further documents are listed in the continuation of Box C.   ☐   See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	
"E" earlier application or patent published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 September 2002 (20.09.2002)	15 NOV 2002
Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
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Form PCT/ISA/210 (second sheet) (July 1998)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US02/10868

Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claim Nos.:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claim Nos.:
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claim Nos.:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
There are two separate inventions. One group comprises claims 1-57 and 75-77 and the other group comprises claims 58-74 and 78-96. One group primarily focuses on in-band and out-of-band detection and the other group primarily focuses on self-correlation.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest ☐ The additional search fees were accompanied by the applicant's protest.
                  ☐ No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (continuation of first sheet(1)) (July 1998)